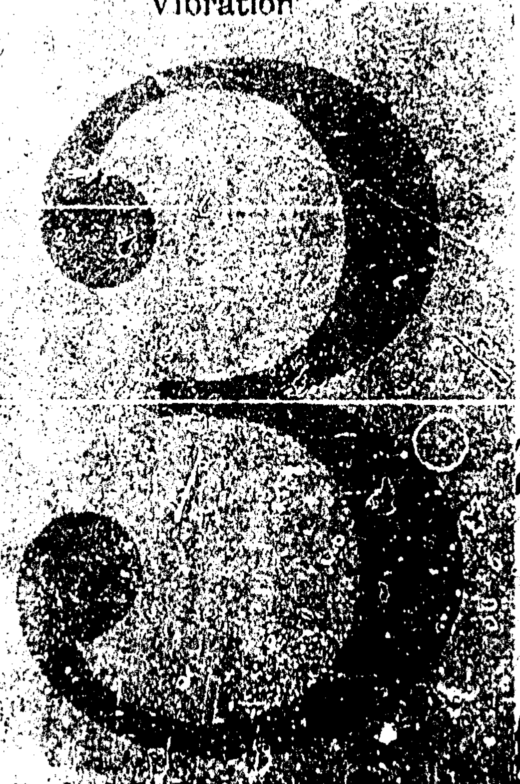
AD 410259

Boeing Wichita
Human Factors

Human Hearing and Speech during Whole Body Vibration



Technical Report
Contract NONR-2...
Office of Naval Research

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Technical Report No. 3

HUMAN HEARING AND SPEECH DURING WHOLE-BODY VIBRATION

Robert J. Teare

Research Accomplished Under
Office of Naval Research
Contract Nonr-2994(00)

"Research On
Low Frequency Vibration Effects
On Human Performance"

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THE BOEING COMPANY
Wichita, Kansas

D3-3512-3 April 1963

ABSTRACT

Binaural thres.. .ds for four tones (500, 1000, 2000, and 4000 cycles per second) and tape recordings of spoken messages were obtained from eight subjects under various conditions of vertical sinusoidal vibration. The vibration frequencies ranged from 1 to 27 cps and were presented at four subjective reaction levels. These data were systematically compared to control data obtained when no vibration was present.

Hearing thresholds were significantly affected by vibration, but the effects were variable from subject to subject and from tone to tone. With one exception, all mean threshold changes fell well within the range of what could be attributed to error of measurement of audiometric thresholds. Since the largest threshold change for any subject under any condition was 7.5 db., the differences were not considered to be of any practical significance within the operational environment.

Rated judgments of change in intelligibility and speech "pattern" were inconclusive because of a lack of spread in the ratings. It was noted by the judges that speech became clipped and appeared in short bursts under certain of the vibration conditions. This was particularly true in those frequency ranges where organ displacement had been anticipated. More definitive work in this area was indicated.

Document Number D3-3512-3 reports the third experiment of a series designed to study vibration effects on human performance. Other experiments will be reported sequentially in the Boeing document series D3-3512. All results will be integrated and summarized in D3-3512-0.

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TABLE OF CONTENTS

(Continued)

LIST OF FIGURES

LIST OF TABLES

IN TEXT | Page

IN APPENDICES

REFERENCES

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2. Boeing Document D3-3512-1, "Human Reaction to Low Frequency Vibration," D. L. Parks and F. W. Snyder, 24 July 1961.

3. Magid, E. G., and Coermann, R. R., "The Reaction of the Human Body to Extreme Vibrations," 1960 Proceedings of the Institute of Environmental Sciences.

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INTRODUCTION

As modern manned systems become more complex, system designers require more and more precise information on how the human component can be expected to perform. Of particular importance to the design engineer is information concerning the speed and accuracy with which an operator can perform critical tasks within the system's environment.

One operational environment of many systems is low frequency vibration. Thus, if an operator is called upon to use coordinated perceptual and motor activity to control the system functions within the environment, data must be obtained which will describe the effects of vibration on these activities. Also, data must be obtained which will describe the effects of vibration on the operator's ability to hear and communicate messages and to monitor and interpret displays.

The experiment reported here is one of a series of Boeing-conducted research studies designed to extend the basic knowledge of the effects of vibration on these various types of operator activity. The earlier experiments in the series are studies of vibration effects on specific, relatively simple, perceptual-motor tasks. The later studies explore the vibration effects on more complex sensory and motor activity.

This report, the third in the series, describes relationships in two areas:

1. Vibration effects on auditory thresholds for tones with frequencies included within the normal speech range (500 - 4000 cps).

2. Vibration effects on spoken message intelligibility and the normalcy of the speech pattern of the speaker.

It is divided into three major sections. The first deals with the general experimental conditions, the second presents the results of the hearing threshold studies, and the third describes the effects of vibration on speech intelligibility.

METHODOLOGY

Experimental Subjects

The subjects used in the present experiment were eight male volunteers who had taken part in previous vibration tests. All were employed by The Boeing Company. Prior to the start of the experiment, all had passed complete physical examinations and were certified as being physically fit.

Vibration Apparatus and the Vibration Environment

The Boeing Human Vibration Facility was used to provide the vibration environment for this study. It is described in more detail in a previous document (Ref. 1). This facility provided vertical sinusoidal vibration at the amplitudes and frequencies required by the study.

An illustration of the test configuration for the subject is presented in Figure 1. A standard aircraft seat was mounted on the platform of the vibration table. Plywood inserts covered with 3/4 inch hard felt were used, instead of seat cushions or parachute packs, to increase fidelity of vibration transmission from the chair to the subject. The subject was secured by a military aircraft lap belt.

An aircraft control column with wheel, used in the tests, was mounted in front of the seat. An instrument display panel was mounted forward of the control column. The distance from the subject's normal eye position to the panel was approximately 28 inches.

Vibration Conditions

Each subject was tested under a variety of conditions. An earlier study had identified four subjective reaction levels to vertical, sinusoidal vibration: Definitely Perceptible, Mildly Annoying, Extremely Annoying, and Alarming (Ref. 2). Sixteen discrete cycle points ranging from 1 through 27 cycles per second (cps) were chosen to be presented at each of the four reaction levels. In all, therefore, 64 vibration conditions were possible. However, only 48 conditions were used in the experiment. Magid and Coermann (Ref. 3) indicated decreased human (physical) tolerance for vibration levels at four to eight cps. Because of these findings, it was felt that possible tissue damage might be generated in the subjects if these cps points were used at the Extremely Annoying and Alarming levels for the length of time required for the experiment. As a result, these cps points at these two levels were left out.

A more precise description of vibration conditions used in the present study is presented in Table I. This table shows the displacement (double amplitude) in inches and acceleration existing under each of the conditions. It should be noted that only eleven cps points were used at level three (Extremely Annoying) and only five cps points were observed at level four (Alarming). Because of the exploratory nature of the study and the danger of possible injury, it was felt that isolated sampling would suffice at these levels. Only five of the eight subjects participated in the testing at the Alarming level.

Experimental Sequence

Prior to beginning the experiment, each subject underwent two training sessions separated by an interval of one week. These sessions were designed to give him a general orientation to the experiment and to familiarize him with the apparatus and the tasks involved.

Each subject completed one test session per week. An average testing session consisted of six vibration conditions and lasted about 60 minutes. It included, in sequence, the activities listed below. The subject was given a pre-test physical examination which involved pulse, blood pressure, and temperature readings. He was fitted with ECG leads (for monitoring during vibration) and then donned flight coveralls which he wore during the testing. He then received his instructions from the experimenter. Prior to being vibrated, speech and hearing data were gathered. These were used as "no vibration" controls against which the "vibration" hearing and speech data for that day would be compared. The test vibration conditions were then presented in random order. Each testing condition was separated by a four-minute rest interval to minimize the cumulative effects of fatigue. Post-vibration data were collected on hearing alone and a post-vibration physical examination followed. This sequence of events was repeated each time a subject was tested and continued until all vibration conditions had been observed. A medical doctor monitored the experimental testing.

TABLE I

VIBRATION CONDITIONS USED IN HEARING AND SPEECH EXPERIMENT*

Frequency		1	1.5	2	3	4	5	6	8	10	12	14	16	18	20	23	27
Level 1	DA	.213	.233	.156	.057	.038	.026	.017	.040	.016	.048	.025	.039	.025	.012	.009	.024
	G	.011	.027	.032	.026	.031	.034	.032	.130	.083	.353	.247	.510	.417	.243	.254	.133
Level 2	DA	3.600	2.574	1.477	.942	.370	.172	.148	.113	.055	.082	.056	.068	.053	.035	.019	.012
	G	.184	.296	.302	.433	.303	.220	.273	.371	.281	.604	.565	.894	.871	.711	.515	.436
Level 3	DA	4.877	3.974	2.803						.103	.118	.079	.096	.068	.055	.027	.024
	G	.249	.457	.573						.526	.871	.796	1.260	1.132	1.129	.737	.878
Level 4	DA		5.792							.145		.110		.085		.034	
	G		.666							.740		1.097		1.408		.919	

*Controlled vibration input: Displacement double amplitude (2A) in inches; and frequency (F) in cycles per second. Acceleration (G): G = .0511 $F^2$2A. Shaded squares indicate conditions not used in this experiment. Subjective Reaction Levels--Level 1: "Definitely Perceptible", Level 2: "Mildly Annoying", Level 3: "Extremely Annoying", Level 4: "Alarming". The accelerations and amplitudes shown above are taken from the data points (Ref. 2, fig. 5) for which actual values were available, rather than from the smoothed curves describing the subjective levels.

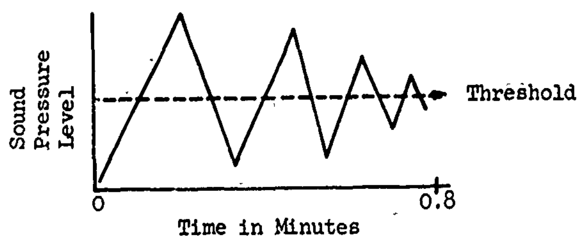
THE HEARING THRESHOLD EXPERIMENT

Obtaining Thresholds

Binaural audiogram thresholds for four tones (500, 1000, 2000 and 4000 cps) were obtained for each subject under the various vibration conditions and for the "no vibration" control conditions. The difference in magnitude between "vibration" and "no vibration" tone thresholds served as the dependent variable in the hearing experiment. These hearing thresholds were obtained as follows.

A Heathkit Signal Generator with motorized volume control was used to generate the tones. The tones were presented to the subject via a binaural headset. The intensity level of the audiometer was under the direct control of the subject. This control, which consisted of a momentary contact switch, was mounted on the right hand grip of the control wheel and was activated by the subject's right middle finger (Figure 1). When the subject closed the switch, the intensity of any given tone would increase as a linear function of time. When opened, the intensity of the tone decreased at the same rate.

The subject was instructed to depress the button until he heard the tone in question; then he was to release it until he no longer heard it. He was instructed to repeat this procedure rapidly. He was stopped by a signal from the experimenter after 0.8 of a minute had elapsed. This procedure resulted in a spiked waveform of tone intensities similar to the one shown below.



The mean value of the various spikes obtained for each trial was taken as the threshold value of that tone.

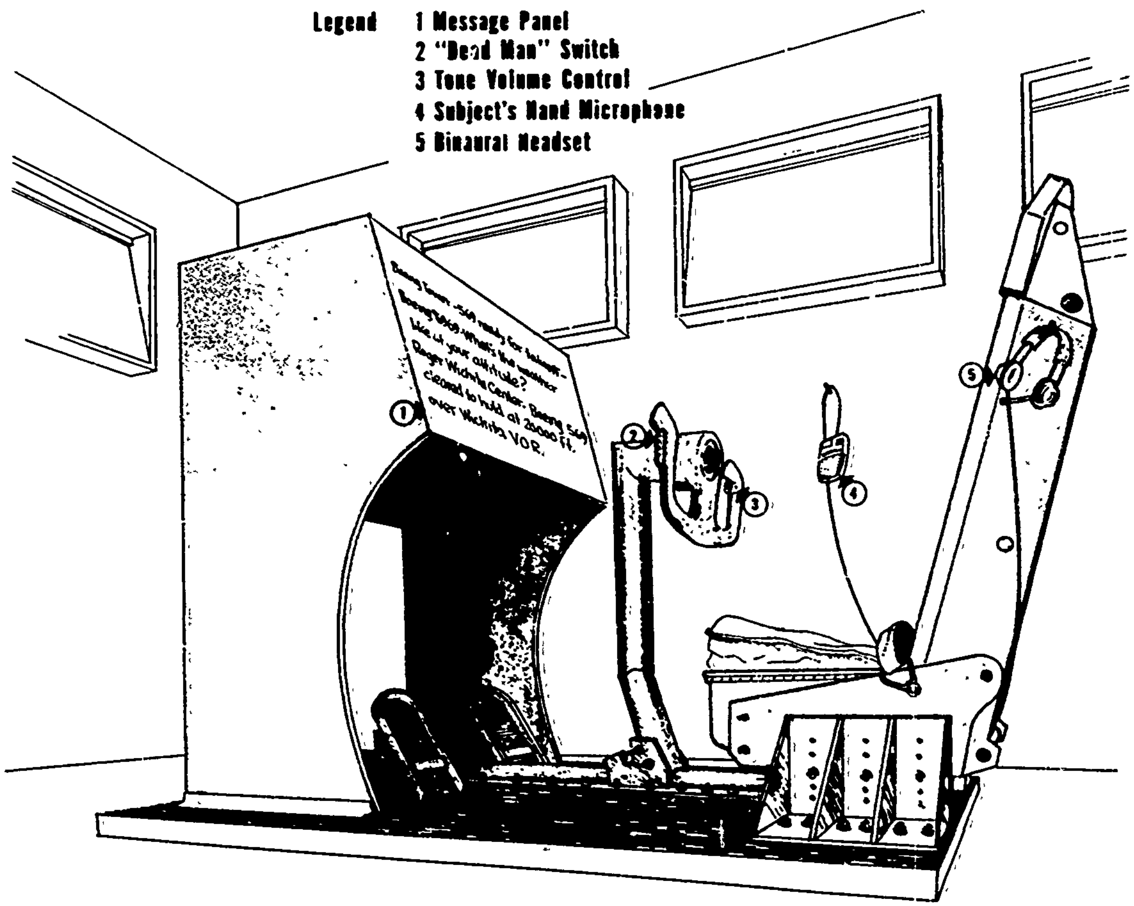
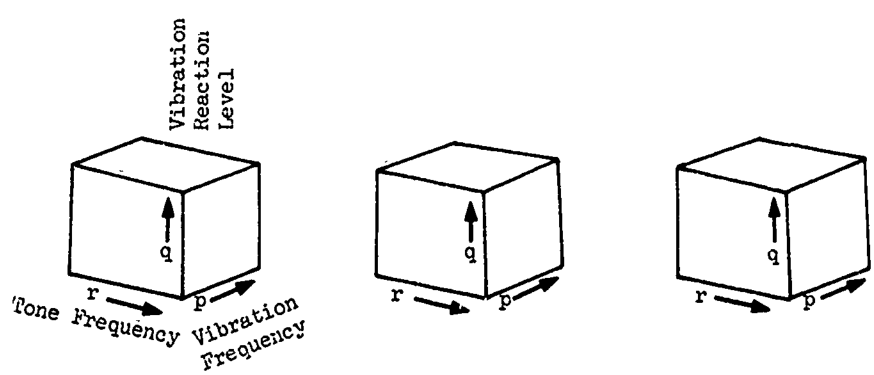


FIGURE 1. SUBJECT'S STATION CONFIGURATION

A "white noise" was inserted during all threshold measurements to mask apparatus noise. This was done regardless of whether the subject was being vibrated. Thus, each audiogram was a hearing threshold for each tone measured against a white noise background. This combined auditory stimulus was fed to the subject's headset via a mixer amplifier connected to the random noise generator (Appendix A). The intensity of the white noise was constant and was shaped to mask those frequencies peculiar to the vibration pump. It had an average value of 80 db (reference to 0.0002 dyne/cm^2).

Data Analysis

Subjects in the hearing experiment were tested under conditions which varied simultaneously with vibration frequency, subjective reaction level, and tone frequency. These data lend themselves to reduction by analysis of variance (ANOV). This analysis contains four dimensions: vibration frequency (with p levels), vibration reaction level (with q levels), tone frequency (with r levels), and subjects (with s levels). The fourth dimension emerges because there were repeated observations at all levels of every factor. The design was thus a "p x q x r" factorial repeated over n subjects (see diagram below).



It should be recalled that not all subjects were observed at all data points. Reaction levels three and four do not contain data from those vibration conditions where possible body damage might have resulted. Furthermore, only five of the eight subjects were tested at the Alarming level. Because of these restrictions, three separate analyses are used.

Analysis I consists of the data generated by observing threshold changes for all eight subjects at only the first two reaction levels (Definitely Perceptible and Mildly Annoying). All combinations of 16 frequencies and four tones are used.

Analysis II contains the data resulting from the observations of threshold changes of the four tones at those frequencies common to reaction levels one, two, and three. Again, all eight subjects were used.

The third analysis restricts itself to threshold changes for the five frequencies that were observed at all four reaction levels. As in the other two analyses, four tone thresholds are used, but here, only five subjects participated. Data are therefore based on the five people who worked at all four levels.

Results and Interpretation

The ANOV summary tables for these three analyses are presented in Tables II, III, and IV, respectively. Although they were analyzed separately, the results are similar enough in character to allow them to be discussed as a unit.

First of all, it can be seen that in none of the three analyses are any of the main effects significant. In all analyses, however, there are statistically significant second order and third order interactions. These can be interpreted as meaning that the influence of any one of the separate dimensions of the experiment (the four main effects) depends entirely on its joint interaction with another dimension. Thus, in Analysis I, the influence of reaction level on threshold change varies from subject to subject. This is indicated by the significant BP interaction term. Furthermore, this phenomenon changes as a function of the tone being presented (significant BCP interaction).

In Analysis II, the frequency of vibration has a differential effect on threshold due to reaction levels (AB interaction). Also, the tones behave differently at different reaction levels and this varies from subject to subject (BCP interaction). In Analysis III, the influence of the subject is again seen in both the AP and ABP interaction terms.

To aid in interpretation of the data, all of the significant triple order interactions involving subjects have been plotted. These are presented in Appendix B. One fact becomes clear from an inspection of these graphs: Individual differences between subjects are the dominant source of variability in the experiment.

TABLE II

ANALYSIS OF VARIANCE TABLE (ANALYSIS I)

(16 FREQUENCIES, 2 LEVELS, 4 TONES, 8 SUBJECTS)

(See Table II-A)

Source of Variability	Sum of Squares	Degrees of Freedom (df)	Mean Square	F or F' Ratio	Significance
A (frequencies)	0.164	15	.011	.0126	--
B (levels)	236.727	1	236.727	2.461	--
C (tones)	518.453	3	172.818	2.603	--
P (subjects)	85.711	7	12.244	.127	--
AB	29.039	15	1.936	.833	--
AC	306.914	45	6.820	.978	--
AP	132.734	105	1.264	.541	--
BC	508.445	3	169.482	.918	--
BP	673.281	7	96.183	7.09	**
CP	1711.773	21	81.513	.442	--
ABC	660.453	45	14.677	1.082	--
ABP	243.977	105	2.324	.[illegible]71	--
ACP	1877.812	315	5.945	.438	--
BCP	3876.422	21	184.592	13.60	**
ABCP	4274.406	315	13.569		

Note: -- = non-significance
** = $p < .01$

TABLE II-A

THE 16 VIBRATION FREQUENCY AND 2 SUBJECTIVE REACTION LEVEL CONDITIONS

USED IN ANALYSIS OF VARIANCE I (TABLE II).

Frequency		1	1.5	2	3	4	5	6	8	10	12	14	16	18	20	23	27
Level 1	**DA**	.213	.233	.156	.057	.038	.026	.017	.040	.016	.048	.025	.039	.025	.012	.009	[illegible]
	G	.011	.027	.032	.026	.031	.034	.032	.130	.083	.353	.247	.510	.417	.243	.254	.133
	DA																
Level 2	**DA**	3.600	2.574	1.477	.942	.370	.172	.148	.113	.055	.082	.056	.068	.053	.035	.019	.012
	G	.184	.296	.302	.433	.303	.220	.273	.371	.281	.604	.565	.894	.871	.711	.515	.436

TABLE III

ANALYSIS OF VARIANCE TABLE (ANALYSIS II)

(11 FREQUENCIES, 3 LEVELS, 4 TONES, 8 SUBJECTS)

(See Table III-A)

Source of Variability	Sum of Squares	Degrees of Freedom (df)	Mean Square	F or F' Ratio	Significance
A (frequencies)	144.937	10	14.5	1.3	--
B (levels)	301.547	2	150.8	3.6	--
C (tones)	653.172	3	217.7	3.5	--
P (subjects)	335.742	7	48.0	1.2	--
AB	130.820	20	6.5	2.1	**
AC	511.437	30	17.1	1.8	*
AP	517.758	70	7.4	2.4	**
BC	340.203	6	56.7	1.0	--
BP	603.547	14	43.1	13.9	**
CP	1228.922	21	58.5	1.0	--
ABC	600.562	60	10.0	.9	--
ABP	438.008	140	3.1	.3	--
ACP	2275.211	210	10.5	.9	--
BCP	2545.711	42	60.4	5.4	**
ABCP	4672.648	420	11.1		

Note: -- = non-significance
* = $p < .05$
** = $p < .01$

TABLE III-A

THE 11 VIBRATION FREQUENCIES AND 3 SUBJECTIVE LEVEL CONDITIONS USED IN ANALYSIS OF VARIANCE II (TABLE III)

Frequency		1	1.5	2						10	12	14	16	18	20	23	27
Level 1	DA	.213	.233	.156						.016	.048	.025	.039	.025	.012	.009	.004
	G	.011	.027	.032						.083	.353	.247	.510	.417	.243	.254	.133
Level 2	DA	3.600	2.574	1.477						.055	.082	.056	.068	.053	.035	.019	.012
	G	.184	.296	.302						.281	.604	.565	.894	.871	.711	.515	.436
Level 3	DA	4.877	3.974	2.803						.103	.118	.079	.096	.068	.055	.027	.024
	G	.249	.457	.573						.526	.871	.796	1.260	1.132	1.129	.737	.878

TABLE IV

ANALYSIS OF VARIANCE TABLE (ANALYSIS III)

(5 FREQUENCIES, 4 LEVELS, 4 TONES, 5 SUBJECTS)

(See Table IV-A)

Source of Variability	Sum of Squares	Degrees of Freedom (df)	Mean Square	F or F' Ratio	Significance
A (frequencies)	208.527	4	52.1	1.30	--
B (levels)	252.750	3	84.2	1.82	--
C (tones)	33.035	3	11.0	(F') .54	--
P (subjects)	117.285	4	29.3	(F') .73	--
AB	301.273	12	25.1	.90	--
AC	253.246	12	21.0	1.29	--
AP	640.695	16	40.0	2.60	**
BC	160.723	9	17.9	1.64	--
BP	588.176	12	49.01	(F') 1.76	--
CP	190.266	12	15.8	.97	--
ABC	279.555	36	7.8	.51	--
ABP	1343.602	48	27.9	1.82	**
ACP	781.660	48	16.3	1.06	--
BCP	663.477	36	18.43	1.20	--
ABCP	2210.453	144	15.35		

Note: -- = non-significance
** = $p < .01$

TABLE IV-A

THE 5 VIBRATION FREQUENCY AND 4 SUBJECTIVE VIBRATION CONDITIONS

USED IN ANALYSIS OF VARIANCE III (TABLE III)

Frequency			1.5							10		14		18		23	
Level 1	DA		.233							.016		.025		.025		.009	
	G		.027							.083		.247		.417		.254	
Level 2	DA		2.574							.055		.056		.053		.019	
	G		.296							.281		.565		.871		.515	
Level 3	DA		3.974							.103		.079		.068		.027	
	G		.457							.526		.796		1.132		.737	
Level 4	DA		5.792							.145		.110		.085		.034	
	G		.666							.740		1.097		1.408		.919	

Implications

The key to the implications of these data lies in the distinction which can be made between practical and statistical significance. The analyses indicate that there are indeed statistically significant effects on the hearing thresholds. The graphs show, however, that the largest threshold change for any subject is 7.5 db. It should be remembered that hearing thresholds, like any other human measurement, are subject to error. Reger (Ref. 4) indicates that the normal standard error of measurement of most audiometric data (within the sound frequency range used here) would be approximately ± 5 decibels. Thus, with one exception, all mean threshold changes in this experiment fall well within the range of what could be attributed to error of measurement. This is especially true in light of the "white noise" background used in the environment during threshold measurement.

There is a further practical consideration of importance here. Noise levels in most operational environments will usually be of such a magnitude as to suggest that the changes observed in this experiment are of little or no consequence. Thus, the observed experimental change is of no practical significance.

THE SPEECH EXPERIMENT

The second major portion of this experimental sequence deals with the determination of the effects of the vibration and subjective reaction level combinations on the speech patterns of the subjects and on the intelligibility of oral message sequences.

The vibration environment and apparatus for this part of the research is the same as that for the hearing. Since these conditions are described in detail in the initial portions of the report, no reiteration is necessary here.

It should be mentioned that this portion of the research is considered to be exploratory. Its main purpose is to determine if comprehensive studies using more precisely controlled experimental techniques and carefully scaled speech passages would be required. If serious distortions of speech patterns and intelligibility are seen, more rigorous experimentation would be the logical next step.

Gathering Speech Data

Speech data were obtained at the beginning of each vibration run. This immediately preceded the gathering of the audiometric data. All data were recorded via a Wollensack T-1500 tape recorder and microphone. To make the recording, the subject picked up the microphone located near his right hand (Figure 1) and, at the experimenter's signal, began his recitation. The subject was instructed to recite a four-line nursery rhyme (Appendix C) from memory. This recitation was followed by a request from the experimenter to read aloud some short air-traffic control phrases. These were read from a card mounted on the display panel. This procedure was repeated for each vibration condition in the experiment and the data derived therefrom constitute the "vibration" speech data. The content of the recitations is presented in Appendix C. The card positioning with respect to the subject can be seen in Figure 1.

"No vibration" speech data, to be used for comparative purposes, were gathered in an identical manner prior to the start of each run. Thus, as in the hearing experiment, the dependent variable was the change in the subject's speech qualities from "vibration" to "no vibration" conditions on a given day.

Determination of Speech Change

The measurement of speech changes were determined subjectively by means of rating procedures. The ratings were made by four trained judges (two Human Factors Engineers and two Acoustical Engineers) on the basis of two separate criteria:

1. Speech intelligibility degradation.

2. Change in "normal" speech pattern.

Intelligibility

Judgments on this dimension were determined as follows. For each subject's test run, the judges were to listen to the recitations for the "vibration" and "no vibration" conditions. As they compared the two, they were to determine how much change, if any, occurred in message intelligibility. The judgments were to be made on the basis of the following five-point scale:

1. No difficulty in understanding (One point).

2. Slightly difficult to understand (Two points).

3. Difficult to understand - listening with care is required (Three points).

4. Very difficult to understand (Four points).

5. Garbled beyond understanding (Five points).

Thus, a rating score ranging from one to five points was obtained from each judge for each of the subjects' vibration conditions.

Speech Pattern

After rating "intelligibility," the judges were then to consider the recitations from the standpoint of "speech pattern" change. No definition of this term was given. Again, the judges were to compare the "vibration" and "no vibration" performance of a given subject and render a judgment on a five-point scale. The scale points were:

1. Not different (One point).

2. Slightly different (Two points).

3. Plainly, unquestionably different (Three points).

4. Very much different (Four points).

5. Totally different from the normal voice without vibration (Five points).

All of the recitation material was presented to the judges in random order with respect to the test conditions and subjects involved. The judges were instructed to make each rating independently of their preceding ratings and were not allowed to refer back to any previous data. The detailed instructions given to the judges are included in Appendix D.

Results

Because of the exploratory nature of this portion of the study, the results are presented only in graphic form. In all cases, the data are plotted across cps points for each of the different reaction levels. The data for intelligibility are presented in Figures 2, 3, 4, and 5. Each data point represents the mean of the four judges' ratings for a given subject at a given treatment combination. Those data profiles for speech pattern change are presented in Figures 6, 7, 8, and 9.

The first consistent result to be seen from an inspection of the intelligibility data is the fact that none of the mean ratings exceeds the two-point value (slightly difficult to understand) except the data point at 10 cps for Reaction Level 4 (Figure 5). There is a tendency for more individual differences to be present as the vibration levels increase. This can be seen from inspection by noting that scatter increases from Level 1 to Level 4. This again reflects the findings from the hearing data that individual variability is the major source of variance in the experiment.

Although no significance tests were carried out, there is a "hint" of another finding embedded in the data. In Levels 1 and 2, the pattern of intelligibility ratings is qualitatively different in the 2 to 8 cps range. No data on these points are available for Levels 3 and 4. More will be said about this in the section on Implications.

The data for these judgments are presented in exactly the same fashion as are those for intelligibility. Again, no significance tests were computed. The most striking qualitative characteristic is the shift in elevation level (mean value) of the profiles from Level 1 to Level 4. The majority of ratings at Reaction Level 4 are above the point where the judges considered the voice patterns to be plainly and unquestionably different.

It should be noted that the ratings of speech pattern at Reaction Level 2 are quite high in the 2 to 10 cps range. This parallels the findings in the intelligibility data. In this range of frequencies, voice pattern variability also is quite large.

Numbers in squares denote subject identification numbers

MEAN INTELLIGIBILITY SCORE	1	1 1/2	2	3	4	5	6	8	10	12	14	16	18	20	23	27
1.75							8									
1.50								6								
1.25									1	4	3		7	7		
1.0	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	1,2,3,4,5,7,8	2,3,4,5,6,7,8	1,2,3,5,6,7,8	1,2,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,8	1,2,3,4,5,6,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8

VIBRATION FREQUENCY (cps)

FIGURE 2 MESSAGE INTELLIGIBILITY AT VIBRATION LEVEL 1 (DEFINITELY PERCEPTIBLE)

MEAN INTELLIGIBILITY SCORE	1	1 1/2	2	3	4	5	6	8	10	12	14	16	18	20	23	27
2.00				2			3	3								
1.75			3	3,5		7	6,7	6		2						
1.50		3	2					1,7		7	2,7	1,3	2	2,7		
1.25		7	7	7	7	1	1		2	3	3,5		3,7		1	
1.0	1,2,3,4,5,6,7,8	1,2,4,5,6,8	1,4,5,6,8	1,4,6,8	1,2,3,4,5,6,8	2,3,4,5,6,8	2,4,5,8	2,4,5,8	1,3,4,5,6,7,8	1,4,5,6,8	1,4,6,8	2,4,5,6,7,8	1,4,5,6,8	1,3,4,5,6,8	2,3,4,5,6,7,8	1,2,3,4,5,6,7,8

VIBRATION FREQUENCY (cps)

FIGURE 3 MESSAGE INTELLIGIBILITY AT VIBRATION LEVEL 2 (MILDLY ANNOYING)

Numbers in squares denote subject identification numbers.

MEAN INTELLIGIBILITY SCORE	1	1 1/2	2	3	4	5	6	8	10	12	14	16	18	20	23	27
2.00			8						2	1		1		2		
1.75									6,7		8	7	5,7			
1.50			2,3						4	4,8	3,7	3		8	2	2
1.25			6						8	2,7	2,6	4,8		6	1,3	1
1.00	1,2,3 4,5,6	1,2,3 4,5,6	1,4,5 7						1,3,5	3,5,6	1,4,5	2,3,5 6	1,2,3 4,6,8	1,3,4 5,7	4,5,6 7,8	3,4,5 6,7,8

VIBRATION FREQUENCY (cps)

FIGURE 4 MESSAGE INTELLIGIBILITY AT VIBRATION LEVEL 3 (EXTREMELY ANNOYING)

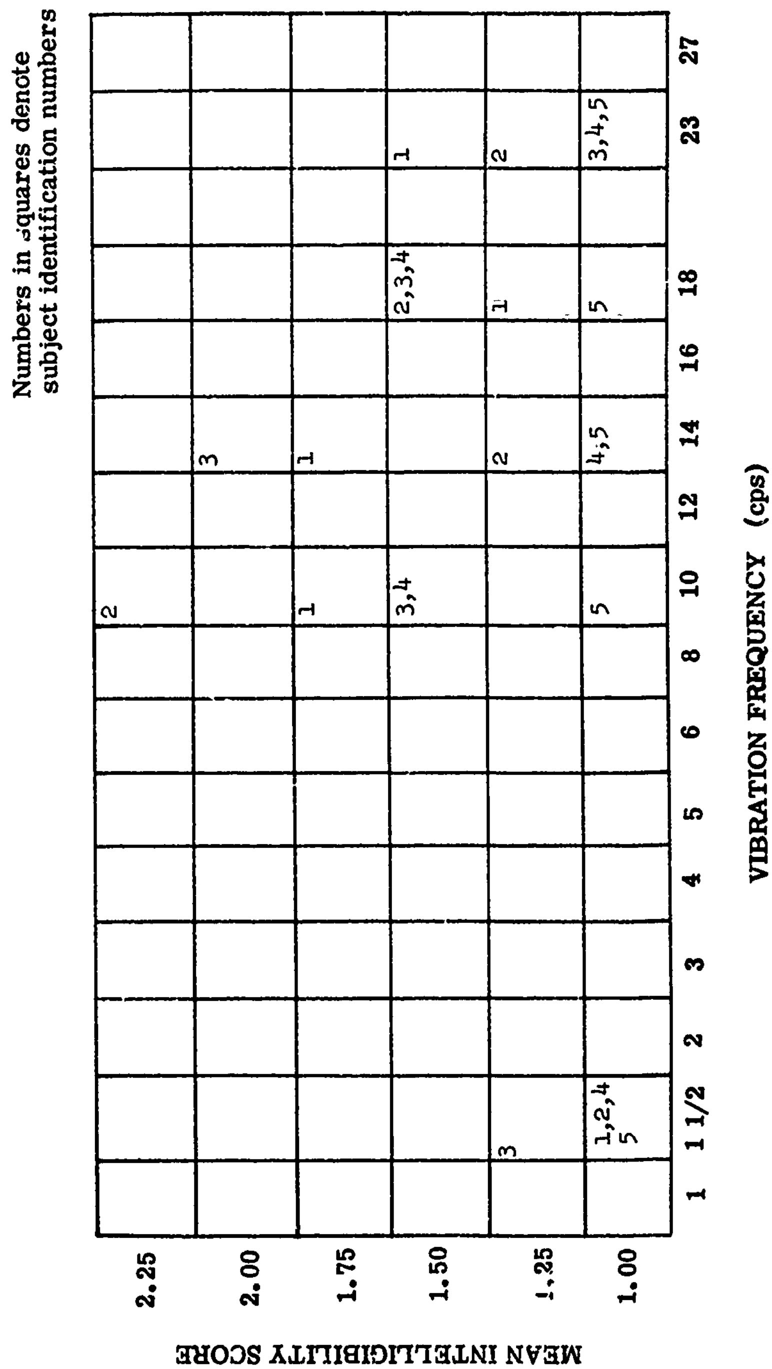


FIGURE 5 MESSAGE INTELLIGIBILITY AT VIBRATION LEVEL 4 (ALARMING)

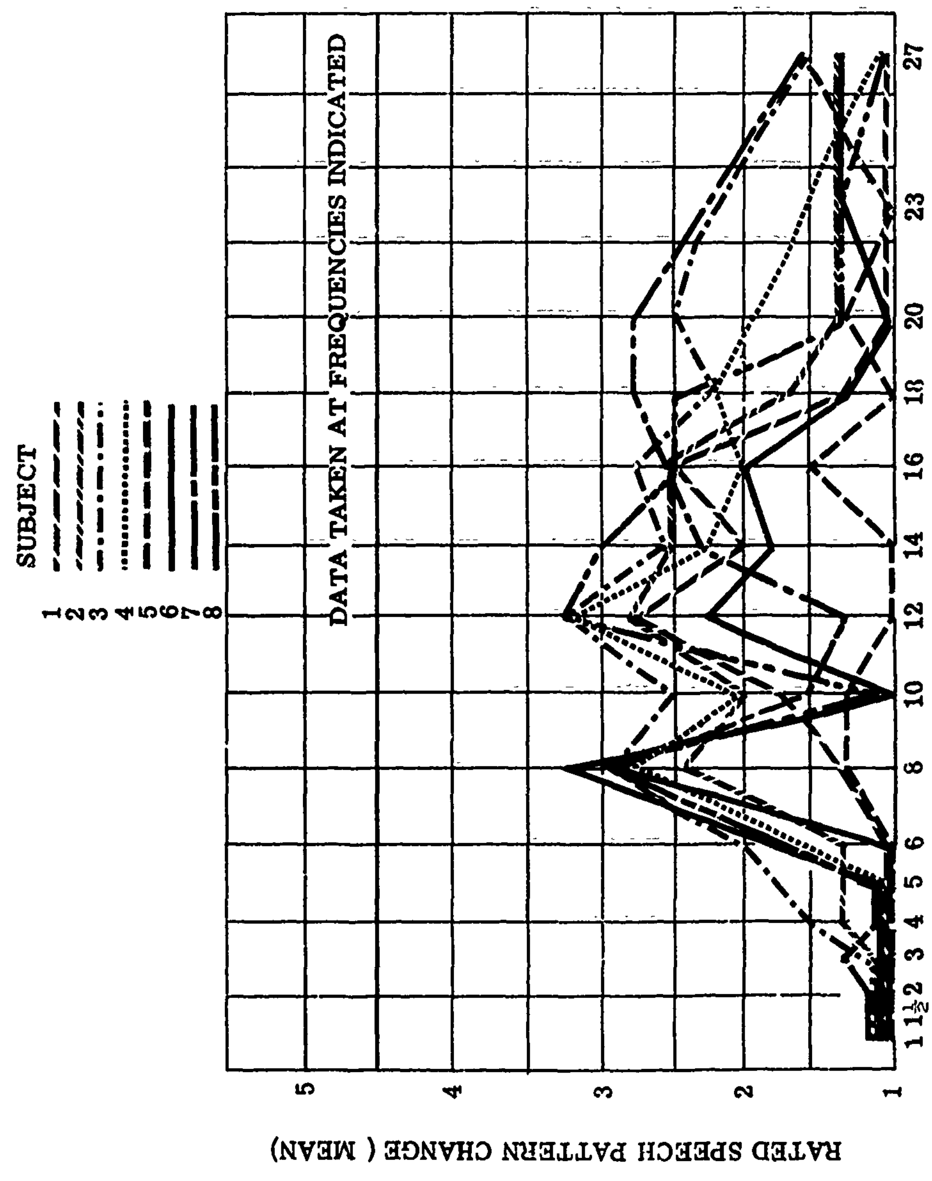


FIGURE 6 SPEECH PATTERN CHANGE AT VIBRATION LEVEL 1
(DEFINITELY PERCEPTIBLE)

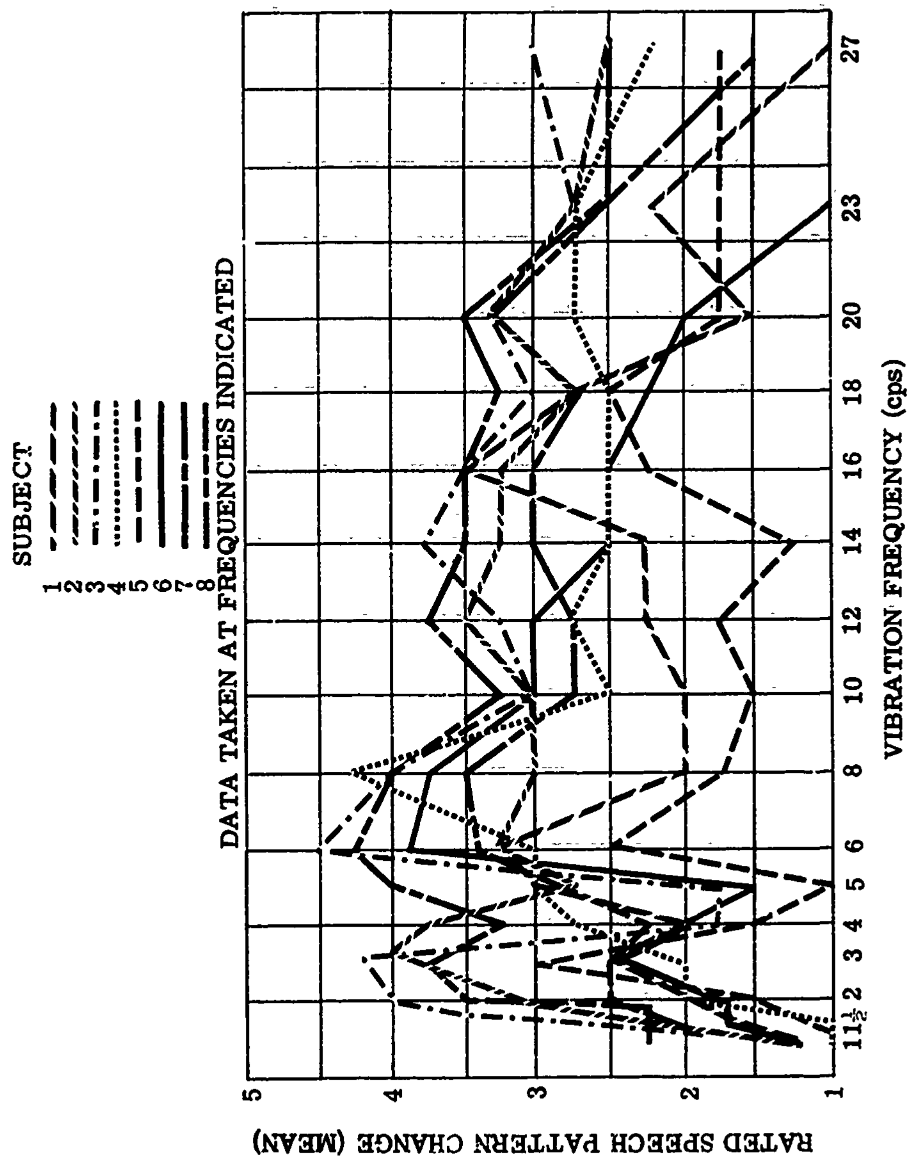


FIGURE 7 SPEECH PATTERN CHANGE AT VIBRATION LEVEL 2 (MILDLY ANNOYING)

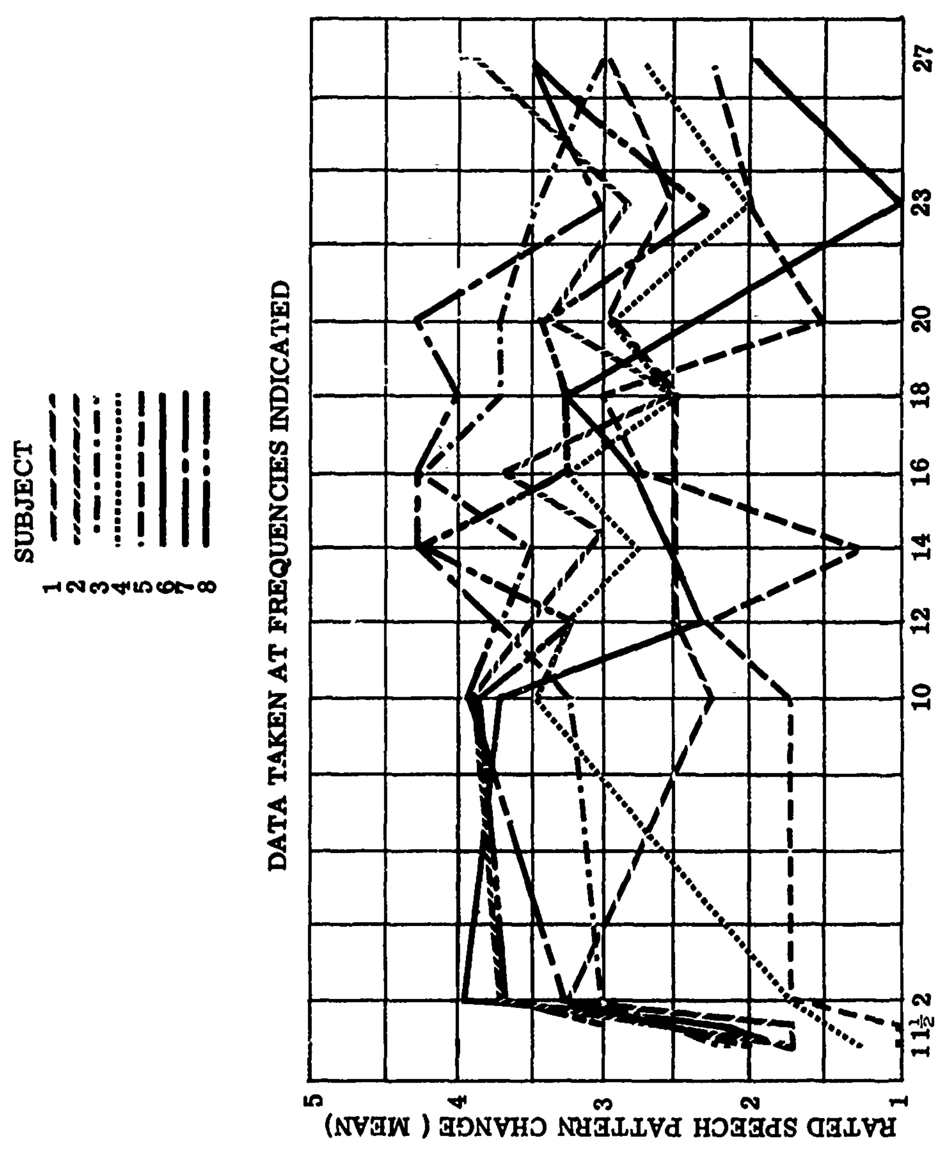


FIGURE 8 SPEECH PATTERN CHANGE AT VIBRATION LEVEL 3 (EXTREMELY ANNOYING)

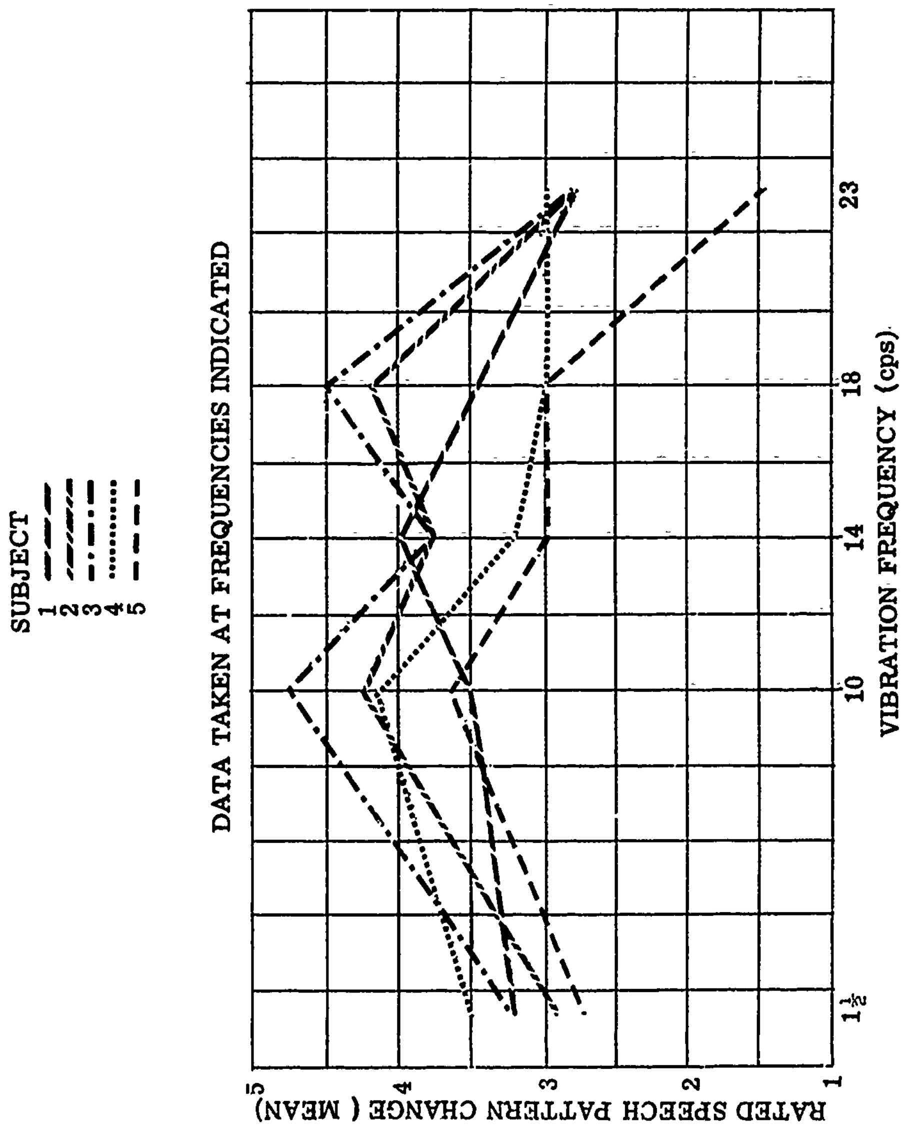


FIGURE 9 SPEECH PATTERN CHANGE AT VIBRATION LEVEL 4 (ALARMING)

Implications

It has been stated previously that the speech section of this report summarizes data from a preliminary, exploratory study. Its findings are presented and summarized in a descriptive and non-quantitative manner. There are two reasons for this:

1. All data are based on subjective ratings on a five-point scale. The question as to whether this measuring device constitutes an interval scale is open to debate. As a result, the use of more sophisticated parametric statistics than those incorporated might be completely unwarranted.

2. Statistics such as correlations and analysis of variance must have variability present in order to be effective. It should be remembered that the ratings were restricted to a maximum point-spread of five units. In the majority of cases, this point spread was not utilized by the raters. This restriction of range would have been reflected in the value of correlations between raters if such values had been used to determine inter-rater agreement. Thus, in Level 1, for example, inter-rater agreement is high simply because very few ratings deviated from the "one point" value. The correlation between raters would have been near zero. This would have occurred because of the lack of spread or variability.

Over and above the statistical considerations, one further point should be mentioned. In all cases, the content of what was recited by the subjects was well known to the judges. There is no doubt that this prior knowledge could have had a restricting effect on the intelligibility ratings. It can be seen from the profiles that there is less variability in these ratings than in those of the speech patterns. Whether this is an artifact of the experiment cannot be answered.

Despite the limitations of the data gathering, some implications for further research are present. More work is needed to explain the ever-present "between subject variability." To dismiss this source of variability as simply "error" variance is to run contrary to the major purposes of this research sequence.

The finding of profile changes in the 2 - 10 cps range should be examined further. In the absence of quantification, no firm conclusions can be made. It is known, however, that this is the frequency range which may be accompanied by severe body organ displacement. Since the diaphragm and vital capacity of the lungs are definitely related

to speech articu`-tion, organ displacement and laryngeal resonance may be one explanation for the statements by the judges that any change in speech pattern seemed to be in the direction of short, clipped phrase bursts. In any event, further work, with an emphasis on tighter input control and physiological measurement related to speech production would seem to be in order on this particular aspect of the problem.

APPENDIX A

ACOUSTICAL APPARATUS

A survey was first conducted to determine noise levels at the subject's head position. Noise primarily results from operation of the vibration table. The most noisy condition is shown in Table A-I. These noise measurements were taken with a General Radio 1551 Sound Level Meter with condenser microphone assembly and a General Radio 1550-A Octave Band analyzer. In order to eliminate the variable masking of signals associated with varying table noise, a constant random noise signal was impressed across the subject's earphones. To lower the required level of the random noise signal below levels of minimum hearing loss criteria (over-all sound pressure level: 90 db.), and still completely mask the variable table noise, a noise protection muff with earphones was used.

The sound level of random noise by octave band required to mask the noise from the vibration table without the use of ear protectors (both discrete and continuous spectrums considered), is shown in Table A-I. Noise reduction or attenuation for the RCA H134/AIC muff communication system used is also shown. Assumed attenuation was chosen below this value because noise attenuation varies. With ear protectors, the required level of random noise to mask vibration table noise is reduced by the amount of attenuation realized by the ear protectors. This is also shown in Table A-I. Sound pressure levels of the random noise signal utilized are given. These levels were measured by inserting a Bruel & Kjaer 4131 microphone face in the plane of the ear protector where the ear auditory canal opening would be when the protector was worn.

Apparatus for measuring changes of pure tone levels required for perception under vibration conditions when compared to no vibration is shown in Figure A-1. Tone frequencies of 500, 1000, 2000, and 4000 cps were used. Gain settings on the random noise generator and the noise amplifier section in the mixer amplifier were set to give the desired noise level for masking of vibration table noise.

More details of the panel control and mixer amplifier are shown in Figures A-2, A-3, and A-4. The level of the pure tone signal was controlled by a switch. This switch operated a motorized potentiometer which increased output voltage of the signal generator when the switch was depressed; voltage output decreased when the switch was not depressed. The voltage output of the signal generator was recorded on the graphic level recorder. The gain of the mixer amplifier was set when the desired pure tone level was obtained in the earphone and held constant throughout the test.

TABLE A-I
SOUND PRESSURE LEVELS BY OCTAVE BAND

Item	20/75	75/150	150/300	300/600	600/1200	1200/2400	2400/4800	4800/9600
Highest sound pressure level (SPL) measured for any vibration condition (1)	102.5	79.5	83	84	82.5	79	85	94
SPL of random noise required to mask vibration table noise without ear protectors	102	84.5	87.5	92	94	90	97	104
Attenuation of RCA H134 (2)		15	16	24	32	35	37	28
Attenuation Assumed		7	8	16	21	24	24	18
SPL of random noise required to mask vibration table noise with ear protection		77.5	71.5	76	73	66	73	76
SPL of random noise used during test	55	63.5	76	82.5	78	72.5	75	65.6

Remarks: (1) f = 16 cps, g = 1.26

(2) These results interpolated from attenuation at frequencies other than octave band mean frequencies.

Note: All values in decibels referenced to sound pressure level 0.0002 dyne/cm^2.

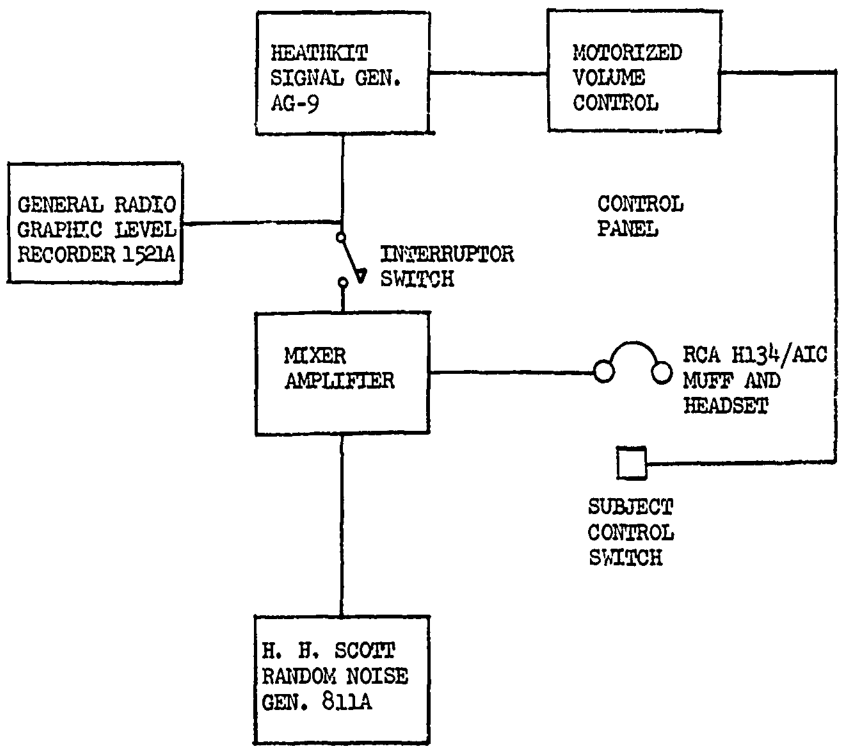


FIGURE A-1. INSTRUMENTATION SYSTEM FOR HEARING EXPERIMENT

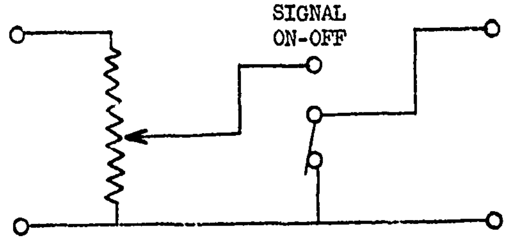


FIGURE A-2. SCHEMATIC OF TONE SIGNAL CONTROL - HEARING EXPERIMENT

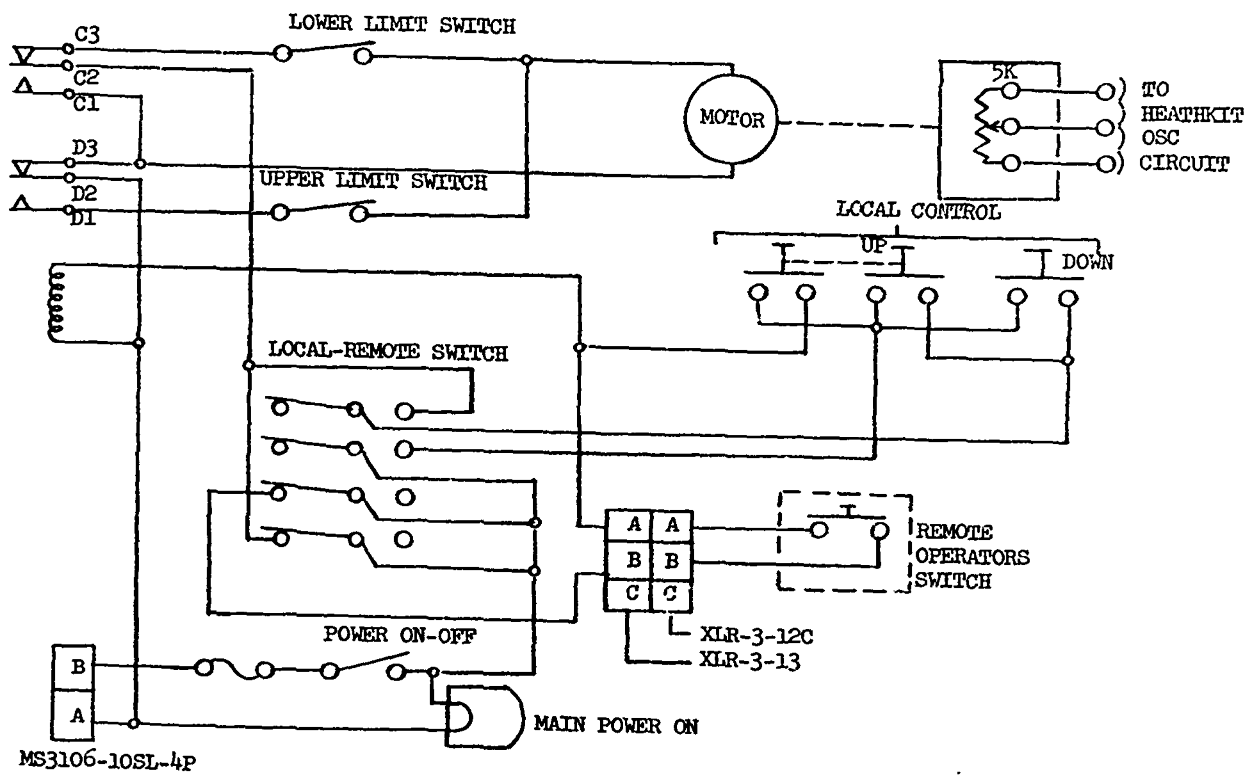


FIGURE A-3. SCHEMATIC OF CONTROL PANEL - HEARING EXPERIMENT

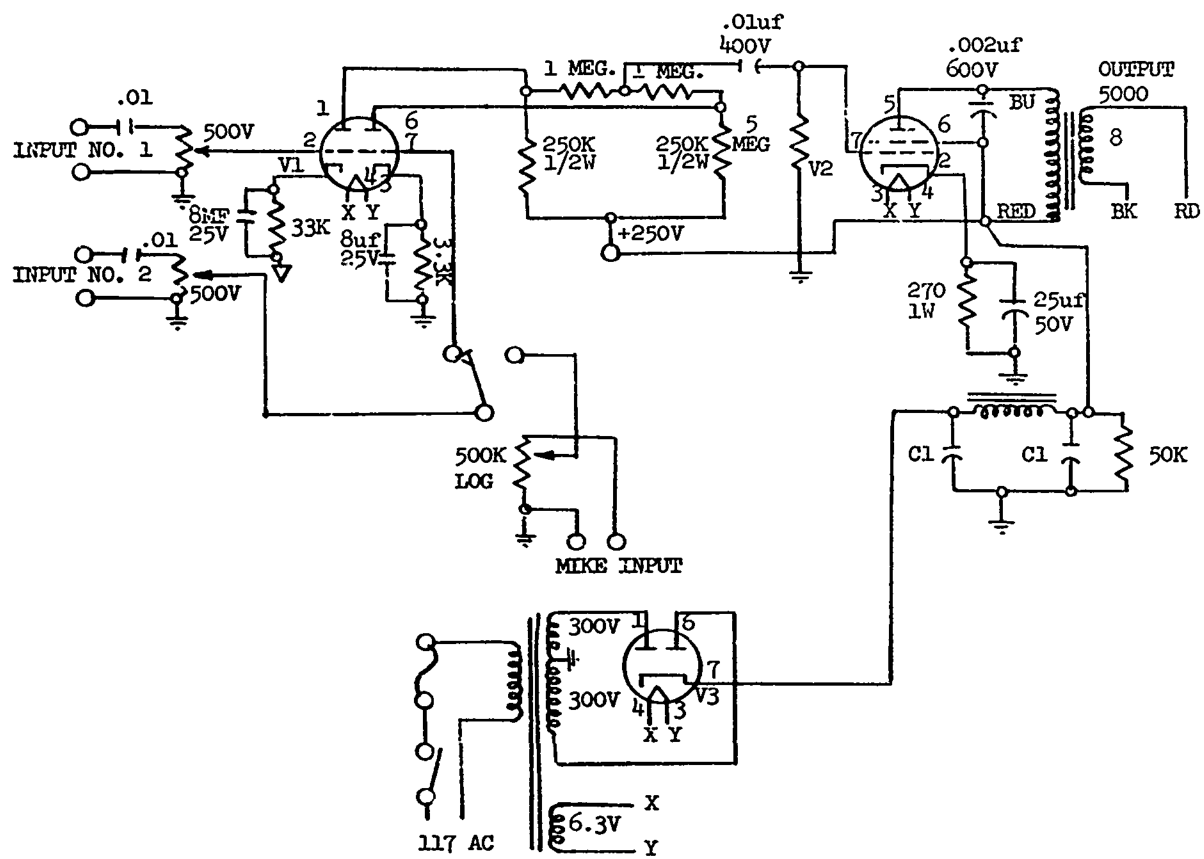


FIGURE A-4. MIXER AMPLIFIER CIRCUIT - HEARING EXPERIMENT

APPENDIX B

GRAPHIC PLOTS OF HEARING THRESHOLD INTERACTION TERMS

(Analyses I, II, and III)

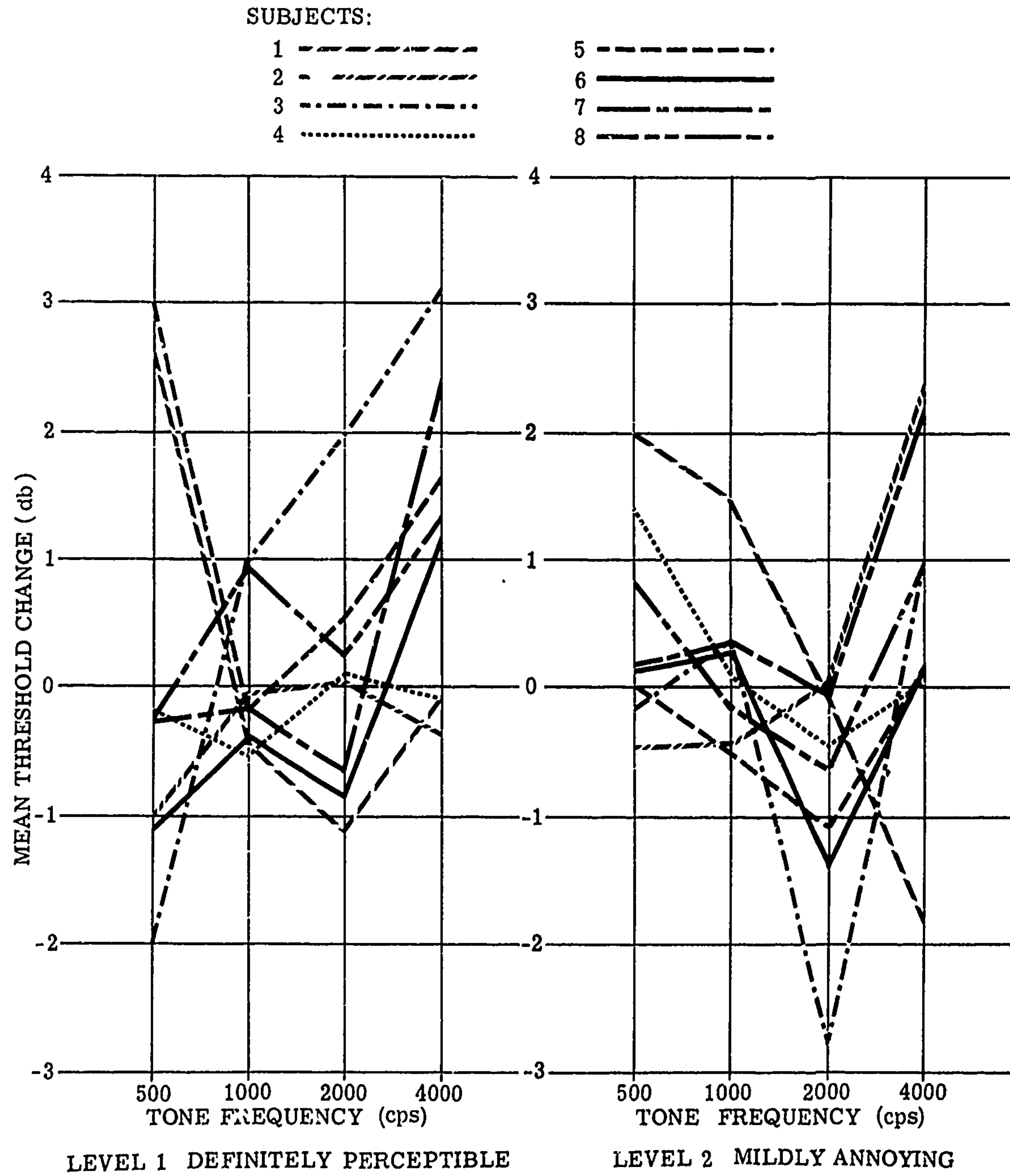


FIGURE B-1 HEARING THRESHOLD ANALYSIS I: BCP INTERACTION TERMS (VIBRATION LEVELS, TONES, SUBJECTS)

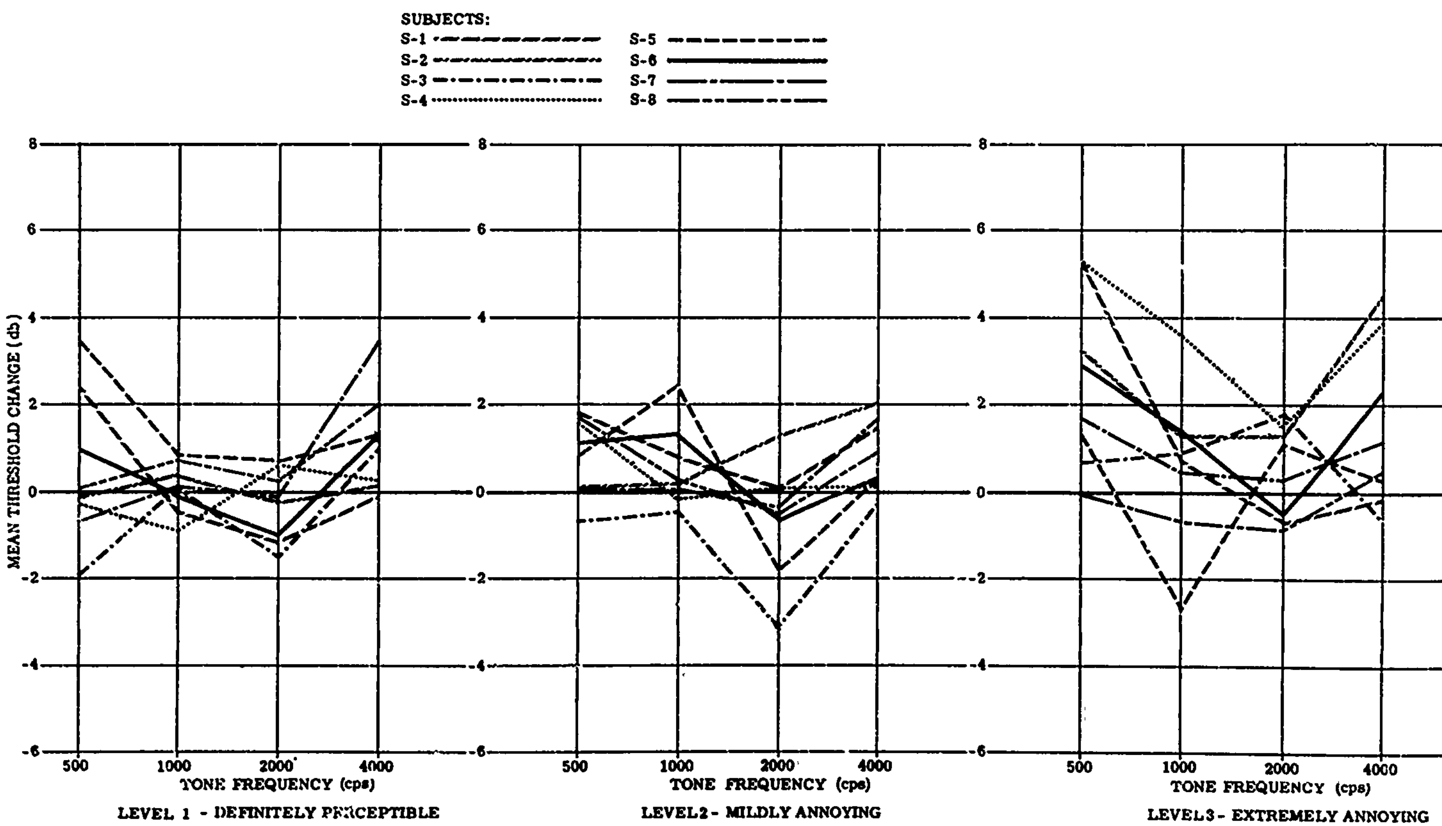


FIGURE B-2 HEARING THRESHOLD ANALYSIS II: BCP INTERACTION TERMS (VIBRATION LEVELS, TONES, SUBJECTS)

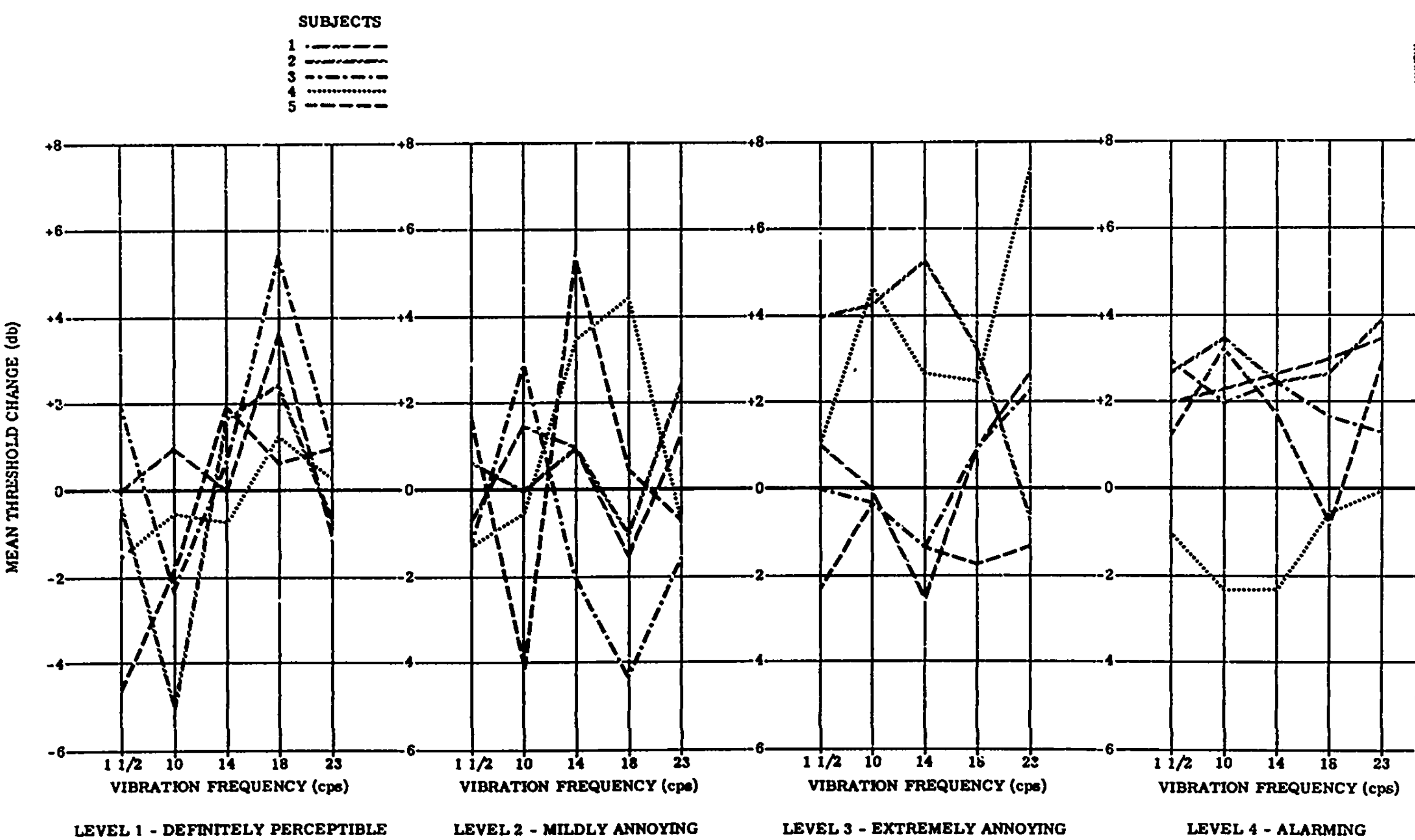


FIGURE B-3 HEARING THRESHOLD ANALYSIS III: ABP INTERACTION TERMS (VIBRATION FREQUENCIES, VIBRATION LEVELS, SUBJECTS).

APPENDIX C

TEXT OF RECITATIONS BY SUBJECTS

The text of the messages was:

Mary had a little lamb
Its fleece was white as snow
And everywhere that Mary went
The lamb was sure to go.

Boeing Tower - 569 ready for take-off.

Boeing #6969 - What's the weather like at your altitude?

Boeing Wichita Center - Boeing 569 cleared to hold at 20,000 feet over Wichita VOR.

APPENDIX D

INSTRUCTIONS TO THE JUDGES

Instructions to judges were as follows:

You will first hear two speech recitations to familiarize yourself with the normal speaking voice (within the limitations of the recording system, etc.) of a subject. Next, you will hear six recitations of the same message (by the same subject) made under differing test conditions. After each test condition is heard, you should form two separate judgments about this condition relative to the normal speaking voice.

The first judgment is formed on the basis of how much the natural voice pattern of the subject was changed by the test condition.

1. If you would judge that the voice pattern is not different from the normal pattern, assign the number one to this test condition on your ballot sheet.

2. If you would judge that the voice pattern seems to be slightly different from the normal pattern, assign the number two to this test condition on your ballot sheet.

3. If you would judge that the voice pattern seems to be plainly, unquestionably, different from the normal pattern, assign the number three to this condition on your ballot sheet.

4. If you would judge that the voice pattern seems to be <u>very much</u> different from the normal pattern, assign the number four to this test condition on your ballot sheet.

5. If you would judge that the voice pattern seems to be totally different from the normal pattern, assign the number five to this test condition on your ballot sheet.

The second judgment is formed on the basis of the intelligibility of the message. This judgment should be made independently of your first judgment. In making this judgment, pretend that you are hearing this message (i.e., recitation) for the first time. Then, if you would judge that:

1. Upon hearing this message for the first time there would be no difficulty in understanding the text, assign the number one to this test condition on your ballot sheet.

2. Upon hearing the message for the first time it would seem slightly difficult to understand, assign the number two to this test condition on your ballot sheet.

3. Upon hearing the message for the first time it would seem to be difficult to understand (if you would have to listen with care to understand its text), assign the number three to this test condition on your ballot sheet.

4. Upon hearing the message for the first time it would seem to be very difficult to understand (if you would have to listen quite carefully to understand its text), assign the number four to this test condition on your ballot sheet.

5. Upon hearing this message for the first time it would seem garbled to the extent that no amount of careful listening would make it understandable, assign the number five to this test condition on your ballot sheet.

APPENDIX E

AUDIOMETRY RESULTS

TABLE E-1

AUDIOMETRY RESULTS

Right Ear

Subject No.	Tone Frequency cps 125	250	500	1000	2000	3000	4000	6000	8000	12000
1	5*	0	0	0	0	0	10	20	5	5
2	10	0	0	0	0	0	0	0	5	5
3	20	5	0	0	0	0	0	0	0	25
4	10	5	5	0	0	0	0	0	0	25
5	0	5	0	0	0	15	20	5	20	35
6	10	5	0	0	10	10	20	30	40	40
7	5	0	0	5	0	0	10	10	0	20
8	10	0	5	0	0	0	20	30	10	40

Left Ear

Subject No.	Tone Frequency cps 125	250	500	1000	2000	3000	4000	6000	8000	12000
1	10*	0	0	0	0	0	5	0	0	10
2	0	0	0	0	0	0	10	15	0	10
3	5	0	5	0	5	5	15	55	0	5
4	30	20	15	5	0	5	10	25	5	40
5	20	5	0	0	0	0	20	15	0	30
6	10	0	0	0	20	30	35	40	35	45
7	5	0	0	0	0	0	10	20	0	20
8	10	5	5	0	0	0	20	30	10	40

*Cell entries = Threshold increase in db relative to statistically normal ear

ACKNOWLEDGEMENT

We wish to thank the following individuals for their participation as volunteer test subjects.

W. D. Fagan
G. D. Goodwin
D. M. Heller
A. E. Lee
A. D. Ogle
C. Praeger
A. A. Sullivan
R. G. Thomas

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